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Balachandreswaran et al.

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(45) **Date of Patent: Oct. 4, 2016**

(54) **PHOTOVOLTAIC GENERATING SYSTEM WITH CONTROL UNIT FOR CONTROLLING OUTPUT POWER CONVERSION AND ACTUATION OF PHOTOVOLTAIC TRACKER UNITS**

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(22) Filed: **Sep. 6, 2012**

(65) **Prior Publication Data**

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Related U.S. Application Data

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G02B 7/04 (2006.01)
H01J 40/14 (2006.01)
G01J 1/02 (2006.01)

(52) **U.S. Cl.**
CPC ***G01J 1/0219*** (2013.01); ***G01J 1/0242*** (2013.01)

(58) **Field of Classification Search**
CPC G01S 3/7861; G01S 3/7862; G01S 3/786; G01S 5/16; G01S 17/66; Y02E 10/50; Y02E 10/52; Y02E 10/56; H02S 10/00; H02S 20/00; H02S 20/10; H02S 20/20; H02S 20/30; H02S 20/32; H02S 30/00; H02S 30/10; H02S 30/20; H02S 40/00; H02S 40/30; H02S 40/32; H02S 40/34; H02S 40/36; H02S 50/00; H02S 50/10; H01L 27/142; H01L 27/144; H01L 27/1446; H01L 31/00; H01L 31/02; H01L 31/02002; H01L 31/02008; H01L 31/04; H01L 31/042; H01L 3131/0445; H01L 31/046; H01L 31/0463; H01L 31/0465; H01L 31/0468; H01L 31/047; H01L 31/0475; H01L 31/05
USPC .... 250/203.1–203.3, 221, 214 R, 214.1, 250/208.2; 136/243–246, 252, 259; 126/569–578, 593, 600–608, 683–713
See application file for complete search history.

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2010/0282293	A1 *	11/2010	Meyer	H01L 31/02008 136/244
2012/0081088	A1 *	4/2012	Park	H02J 7/345 323/282

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Primary Examiner — Pascal M Bui Pho
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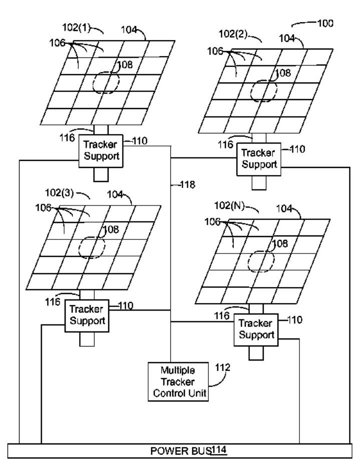
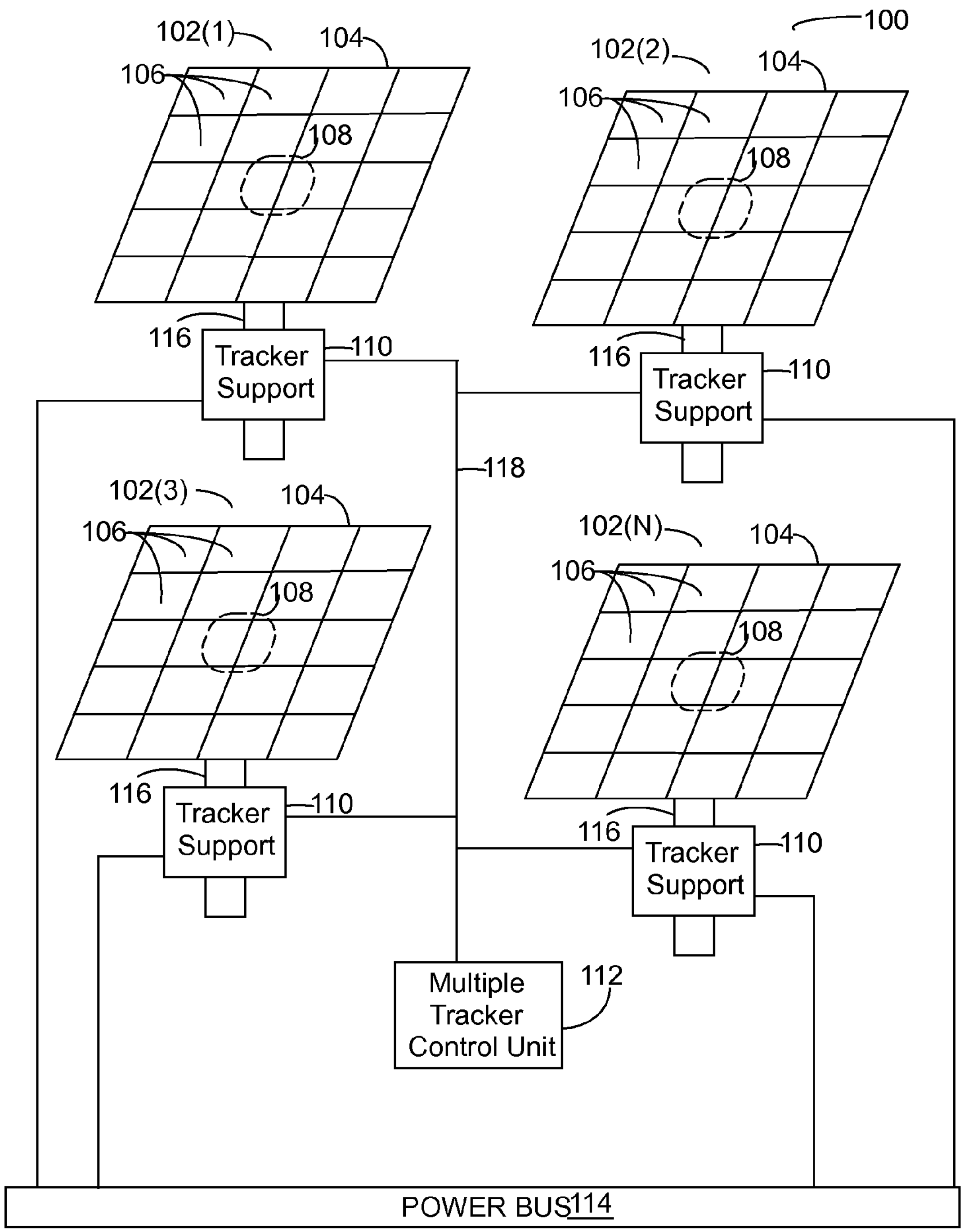
(57) **ABSTRACT**

A photovoltaic (PV) generating system that includes a plurality of PV tracker units, each having: a PV panel with a plurality of PV generators connected to output electrical power and an actuator for positioning the PV panel. A multiple tracker control unit is in communication with the plurality of PV tracker units, the tracker control unit monitoring the output electrical power of the PV panels and controlling, in dependance on the monitored output electrical power, both: (i) power conversion of the output electrical power and (ii) the actuators of the PV tracker units, to optimize power output for the plurality of PV tracker units.

19 Claims, 14 Drawing Sheets





100
102(1)
104
106
108
116
Tracker Support
110
102(2)
104
106
108
116
Tracker Support
110
118
102(3)
104
106
108
116
Tracker Support
110
102(N)
104
106
108
116
Tracker Support
110
Multiple Tracker Control Unit
112
POWER BUS 114

FIG. 1

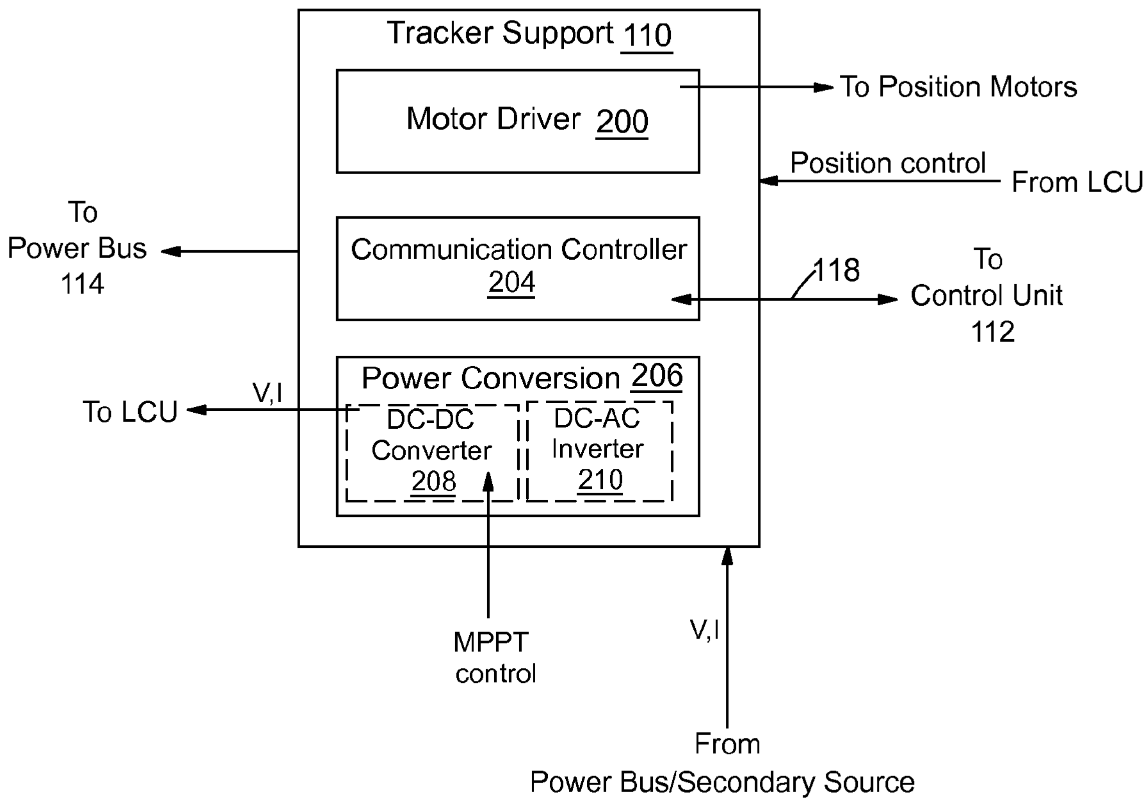

Tracker Support 110
Motor Driver 200
To Position Motors
Position control
From LCU
To
Power Bus
114
Communication Controller
204
118
To
Control Unit
112
Power Conversion 206
V,I
To LCU
DC-DC
Converter
208
DC-AC
Inverter
210
MPPT
control
V,I
From
Power Bus/Secondary Source

FIG. 2

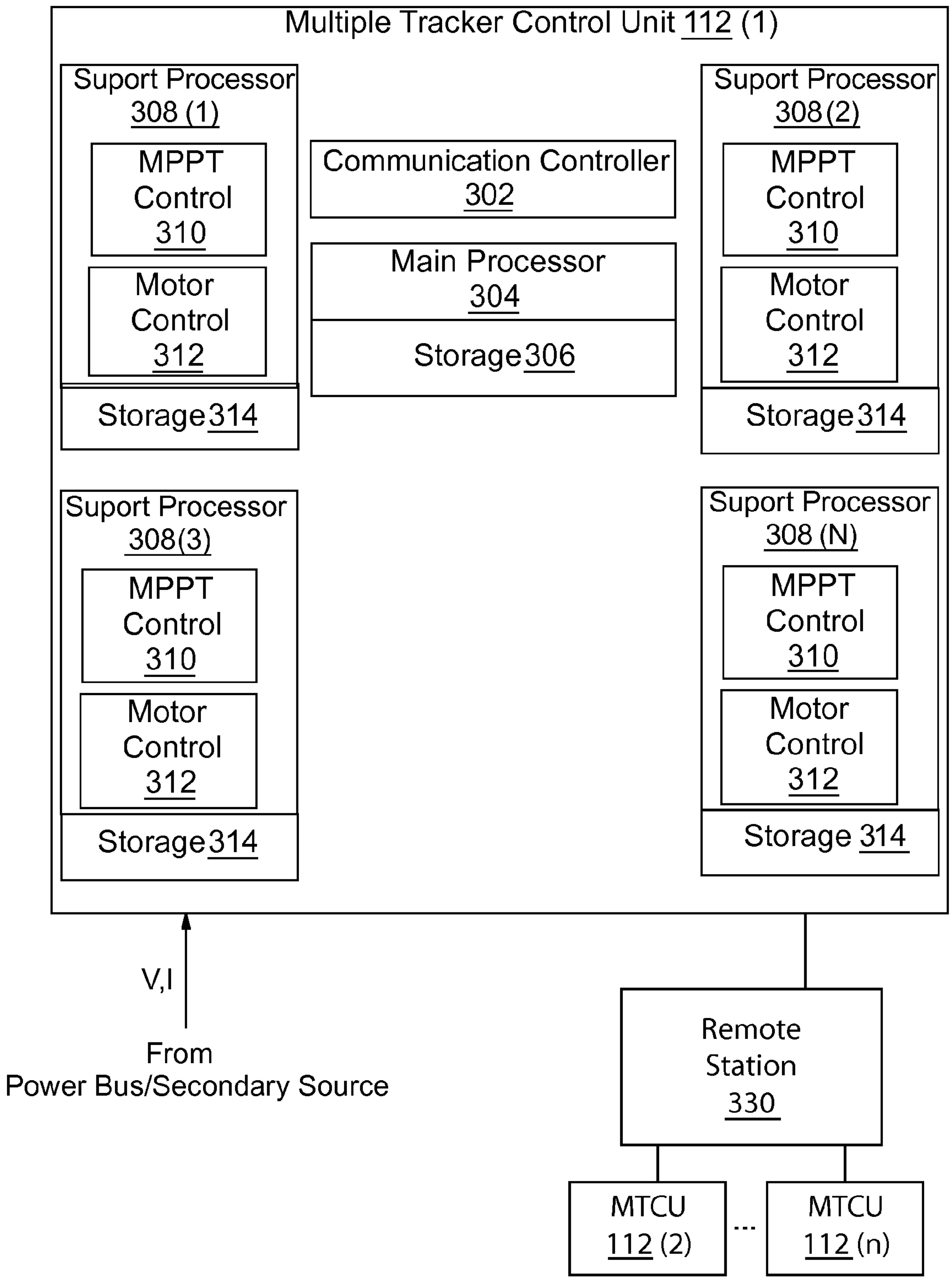

Multiple Tracker Control Unit 112 (1)
Suport Processor 308 (1)
MPPT Control 310
Motor Control 312
Storage 314
Communication Controller 302
Main Processor 304
Storage 306
Suport Processor 308 (2)
MPPT Control 310
Motor Control 312
Storage 314
Suport Processor 308(3)
MPPT Control 310
Motor Control 312
Storage 314
Suport Processor 308 (N)
MPPT Control 310
Motor Control 312
Storage 314
V,I
From Power Bus/Secondary Source
Remote Station 330
MTCU 112 (2)
...
MTCU 112 (n)

FIG. 3

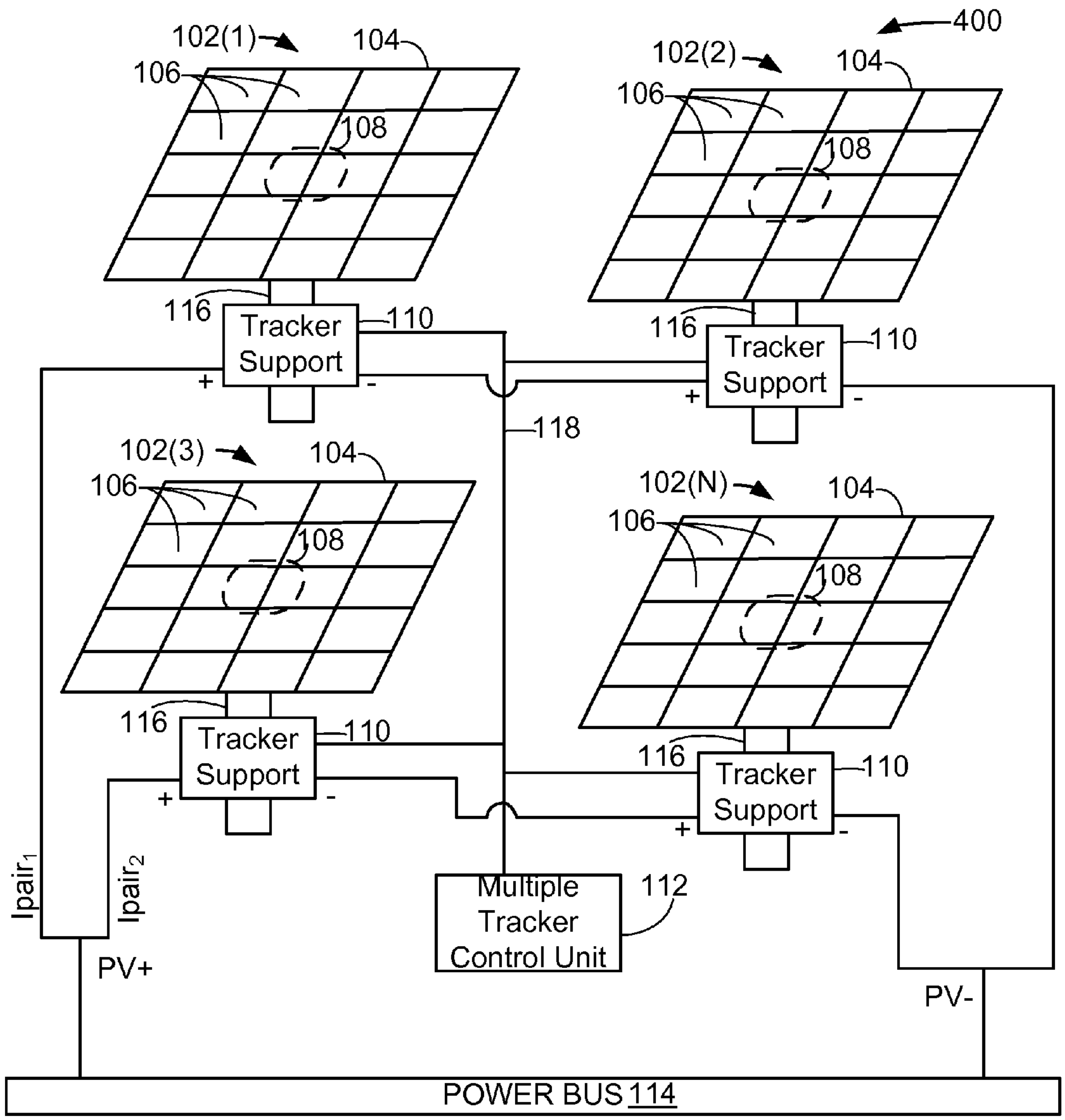

400
102(1)
104
106
108
116
Tracker Support
110
+
-
102(2)
104
106
108
116
Tracker Support
110
+
-
118
102(3)
104
106
108
116
Tracker Support
110
+
-
102(N)
104
106
108
116
Tracker Support
110
+
-
Multiple Tracker Control Unit
112
Ipair1
Ipair2
PV+
PV-
POWER BUS 114

FIG. 4

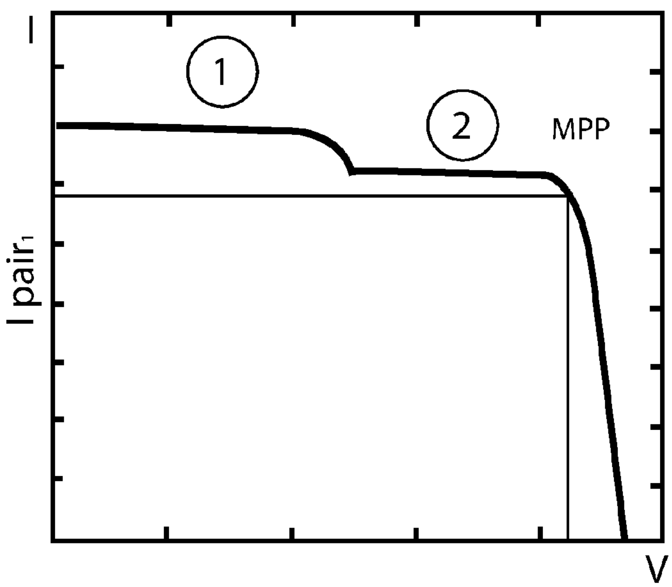


Fig. 5A

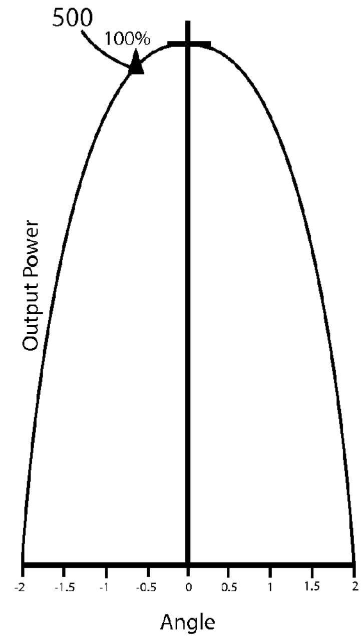


Fig. 5B

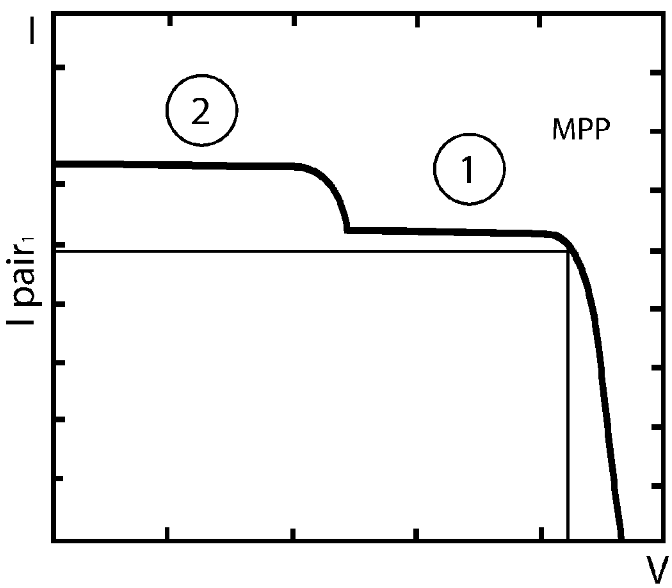


Fig. 6A

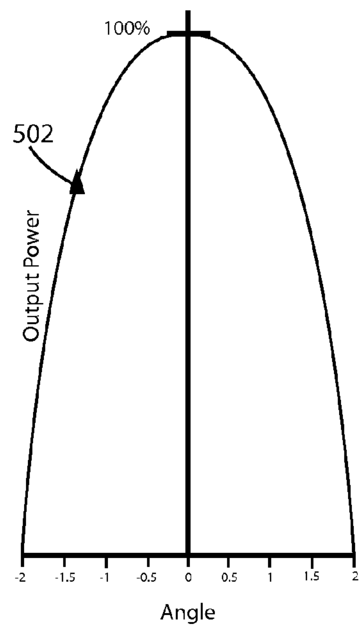


Fig. 6B

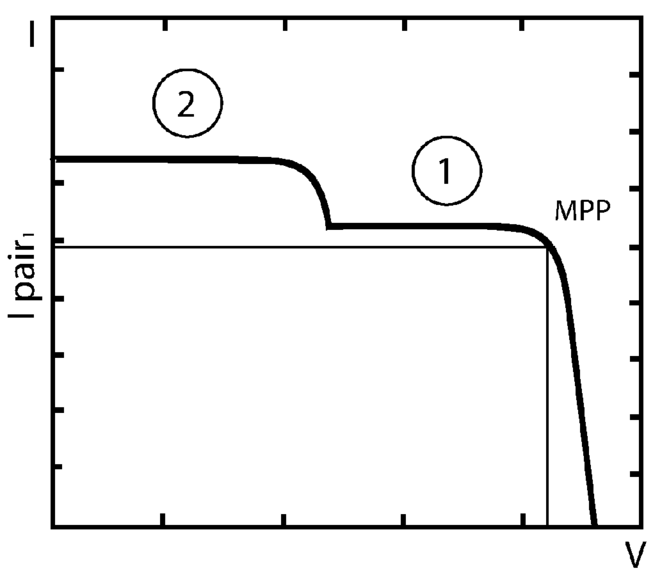


Fig. 7A

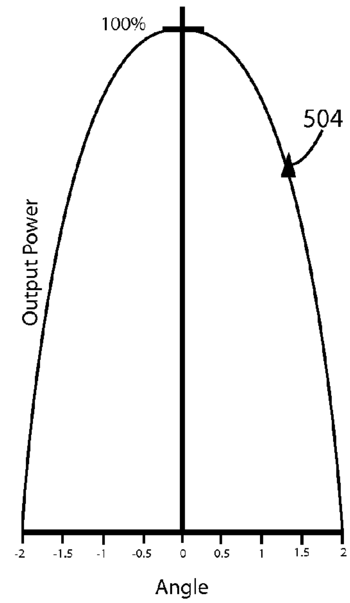


Fig. 7B

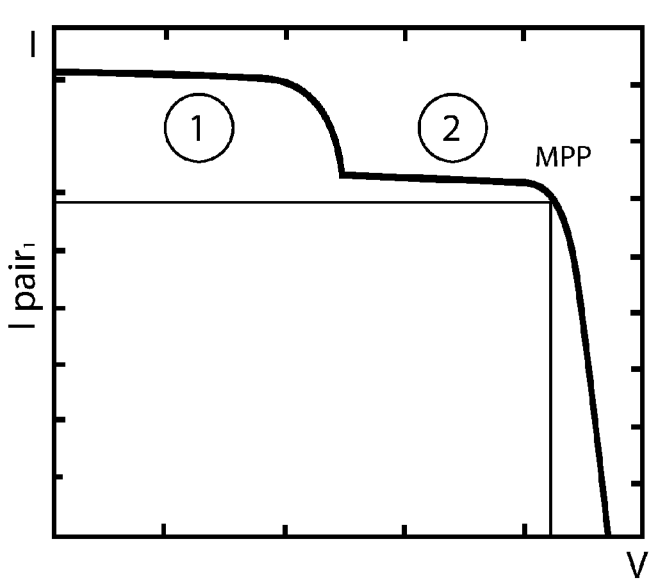


Fig. 8A

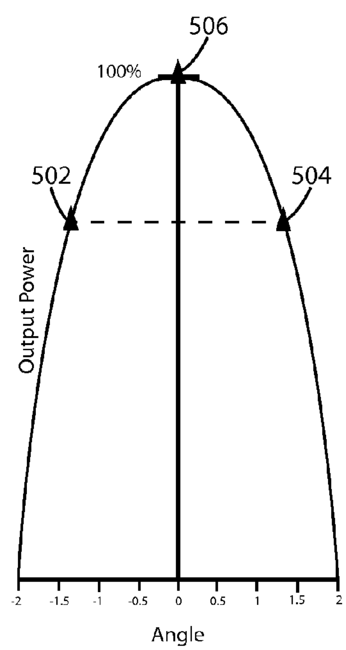


Fig. 8B

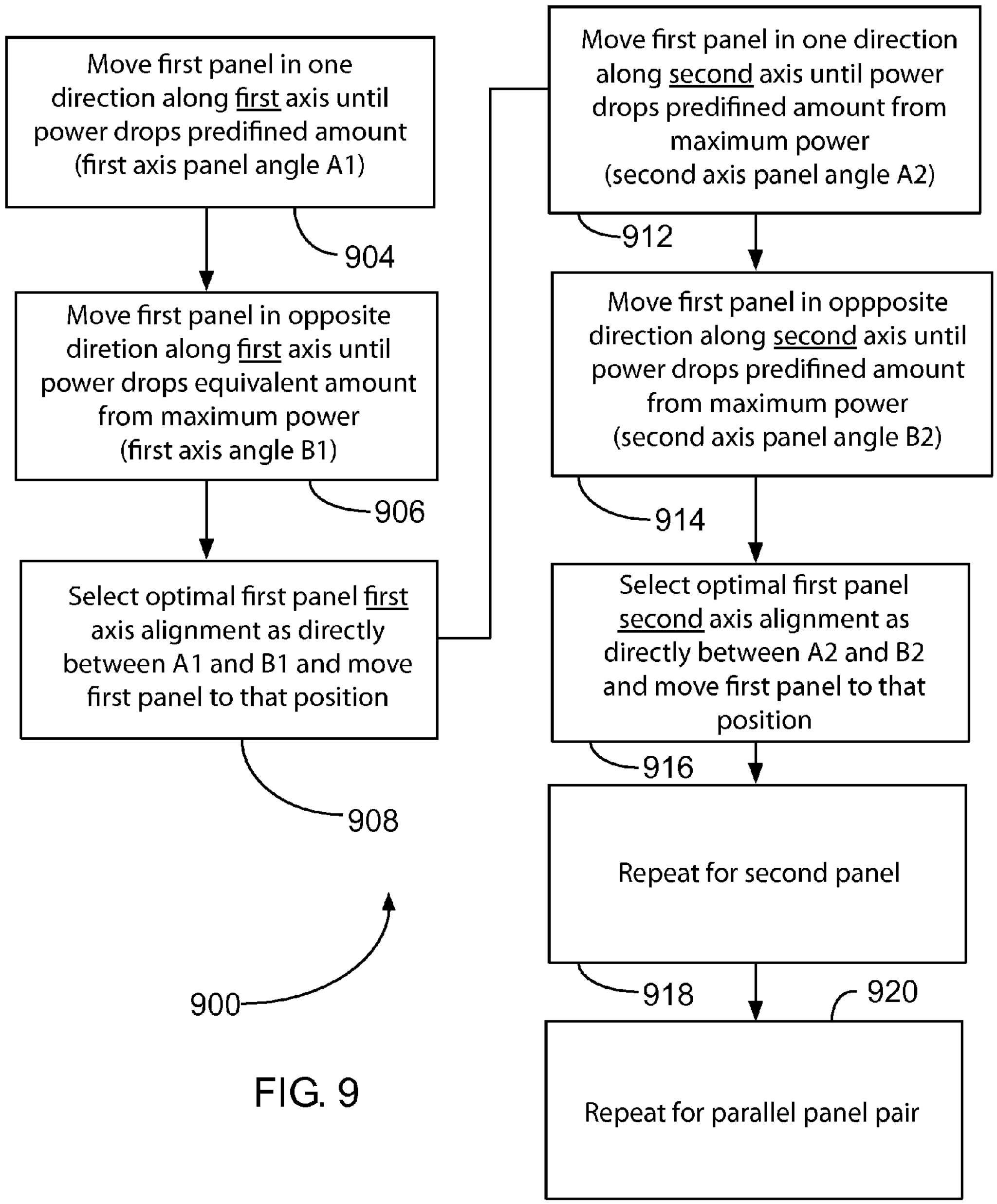

Move first panel in one direction along first axis until power drops predifined amount (first axis panel angle A1)
904
Move first panel in opposite diretion along first axis until power drops equivalent amount from maximum power (first axis angle B1)
906
Select optimal first panel first axis alignment as directly between A1 and B1 and move first panel to that position
908
900
Move first panel in one direction along second axis until power drops predifined amount from maximum power (second axis panel angle A2)
912
Move first panel in oppposite direction along second axis until power drops predifined amount from maximum power (second axis panel angle B2)
914
Select optimal first panel second axis alignment as directly between A2 and B2 and move first panel to that position
916
Repeat for second panel
918
920
Repeat for parallel panel pair

FIG. 9

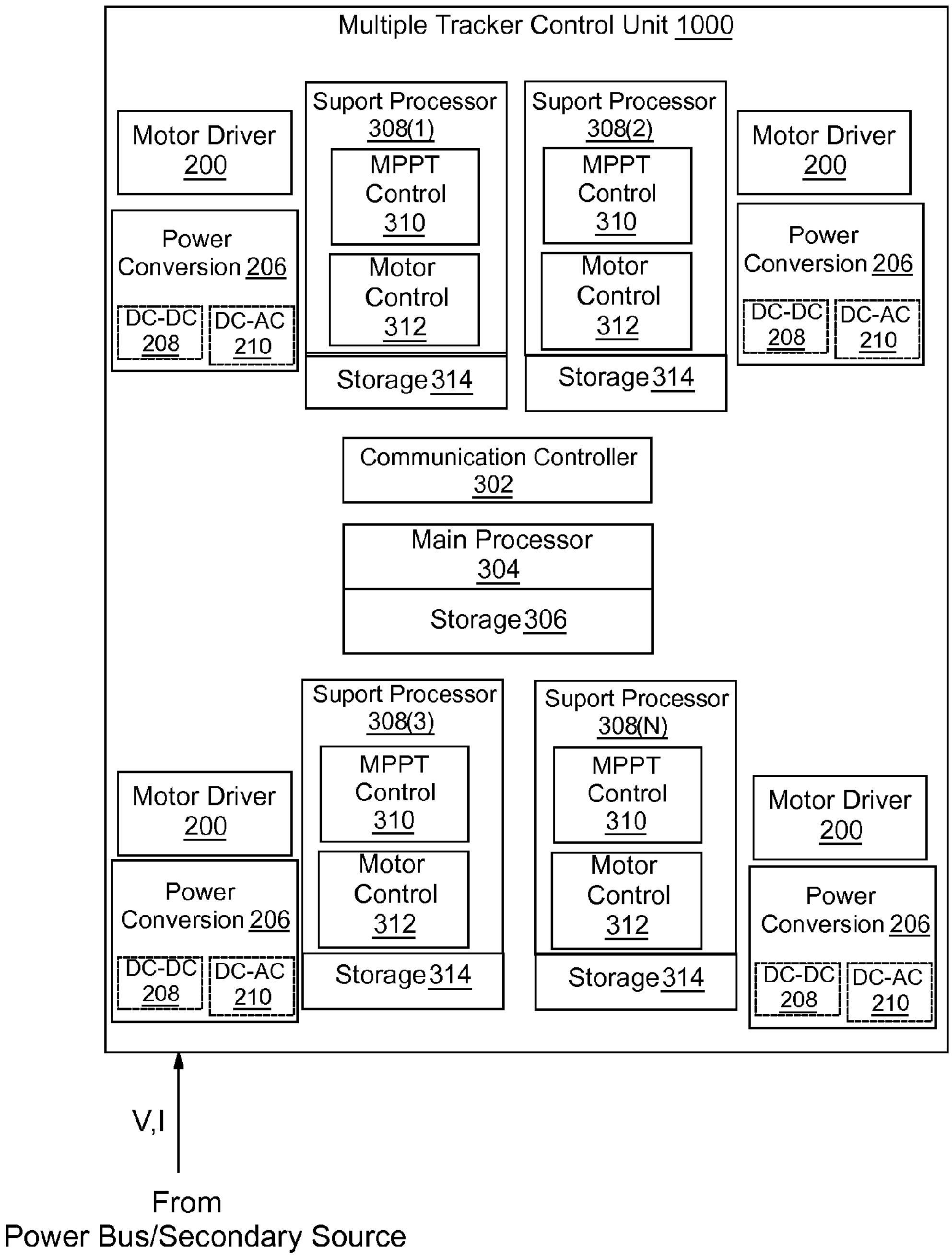

Multiple Tracker Control Unit 1000
Motor Driver 200
Power Conversion 206
DC-DC 208
DC-AC 210
Suport Processor 308(1)
MPPT Control 310
Motor Control 312
Storage 314
Suport Processor 308(2)
MPPT Control 310
Motor Control 312
Storage 314
Motor Driver 200
Power Conversion 206
DC-DC 208
DC-AC 210
Communication Controller 302
Main Processor 304
Storage 306
Motor Driver 200
Power Conversion 206
DC-DC 208
DC-AC 210
Suport Processor 308(3)
MPPT Control 310
Motor Control 312
Storage 314
Suport Processor 308(N)
MPPT Control 310
Motor Control 312
Storage 314
Motor Driver 200
Power Conversion 206
DC-DC 208
DC-AC 210
V,I
From
Power Bus/Secondary Source

FIG. 10

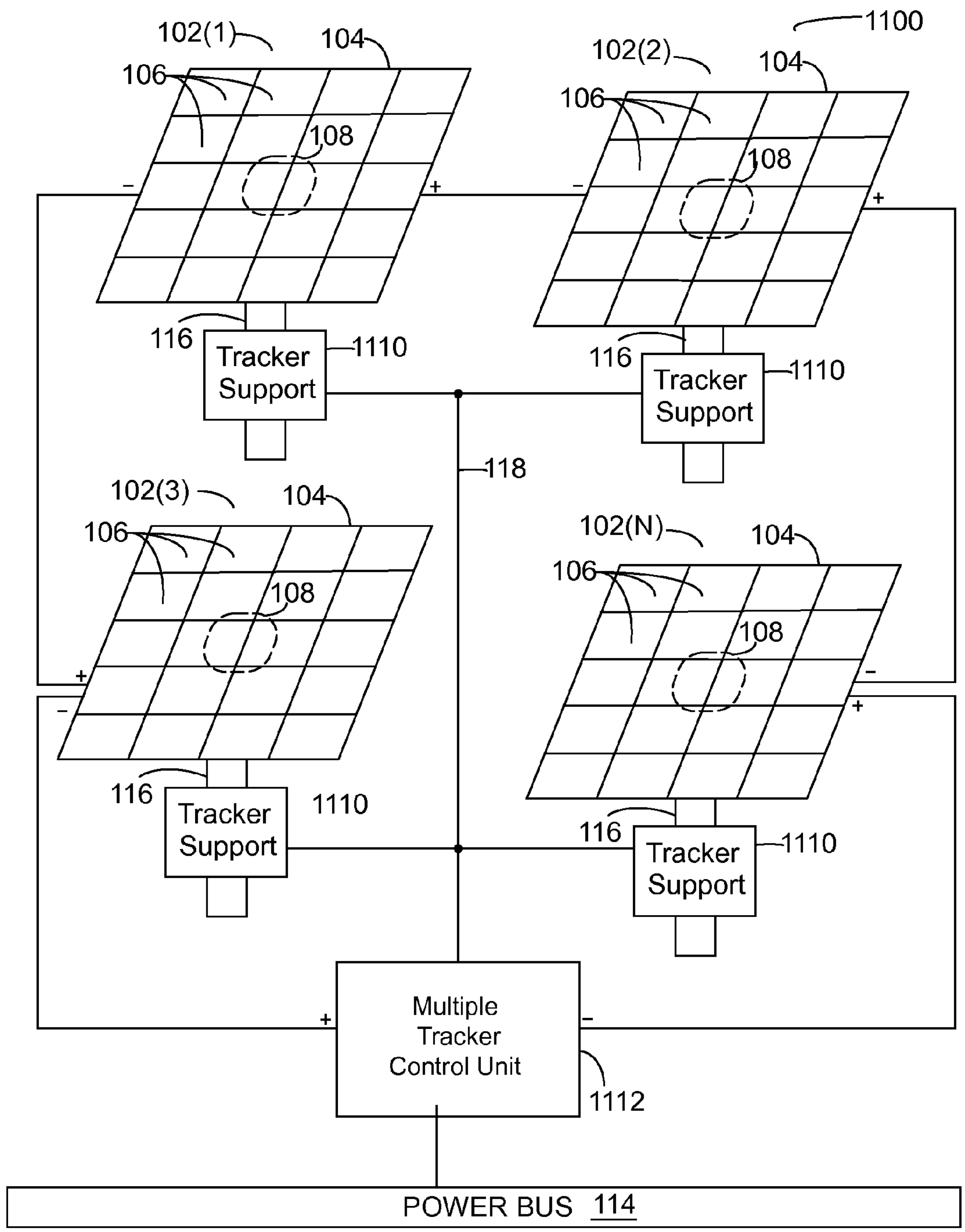

1100
102(1)
104
106
108
116
Tracker Support
1110
102(2)
104
106
108
116
Tracker Support
1110
118
102(3)
104
106
108
116
Tracker Support
1110
102(N)
104
106
108
116
Tracker Support
1110
Multiple Tracker Control Unit
1112
POWER BUS 114

FIG. 11

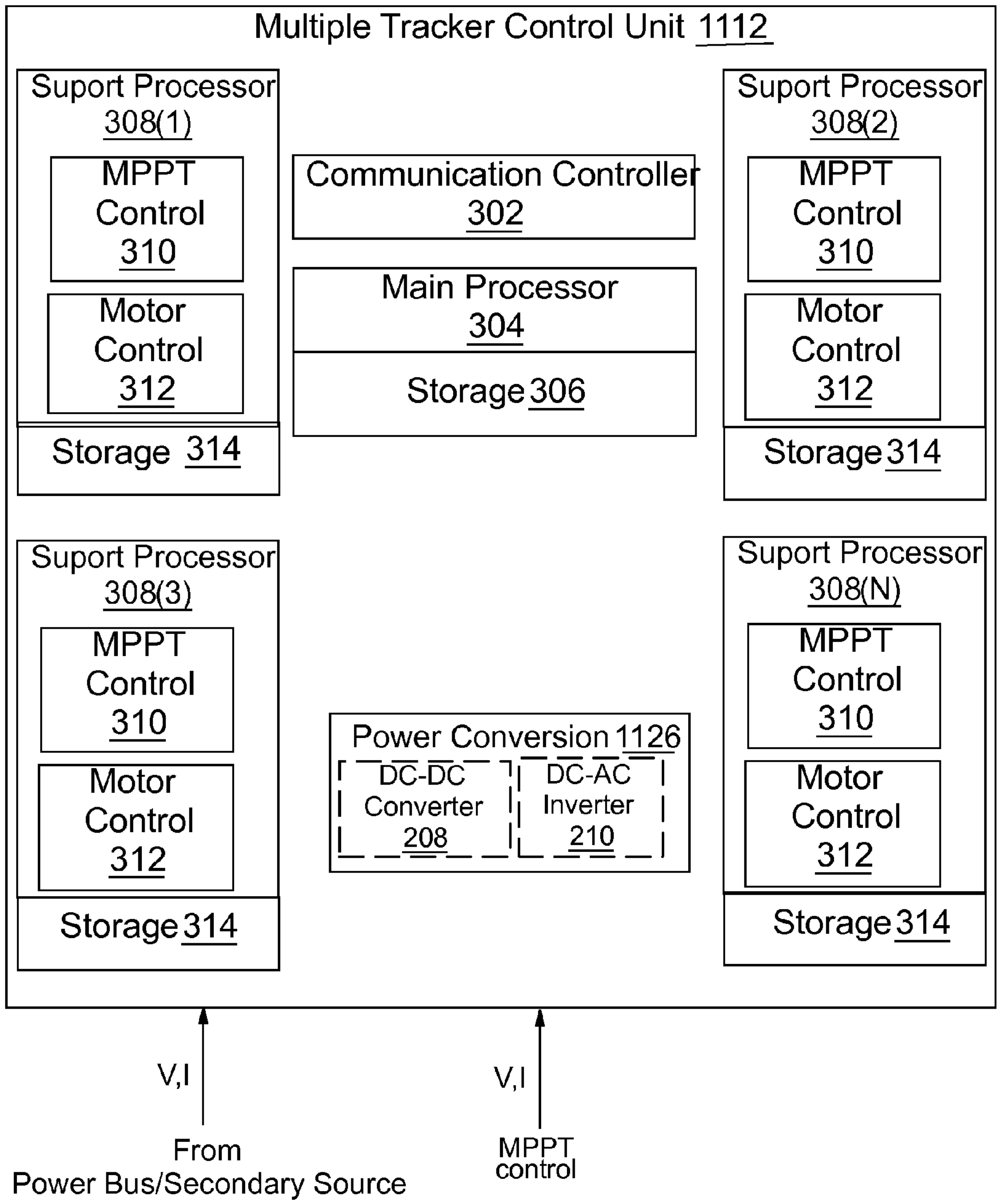

Multiple Tracker Control Unit 1112
Suport Processor 308(1)
MPPT Control 310
Motor Control 312
Storage 314
Communication Controller 302
Main Processor 304
Storage 306
Suport Processor 308(2)
MPPT Control 310
Motor Control 312
Storage 314
Suport Processor 308(3)
MPPT Control 310
Motor Control 312
Storage 314
Power Conversion 1126
DC-DC Converter 208
DC-AC Inverter 210
Suport Processor 308(N)
MPPT Control 310
Motor Control 312
Storage 314
V,I
V,I
From Power Bus/Secondary Source
MPPT control

FIG. 12

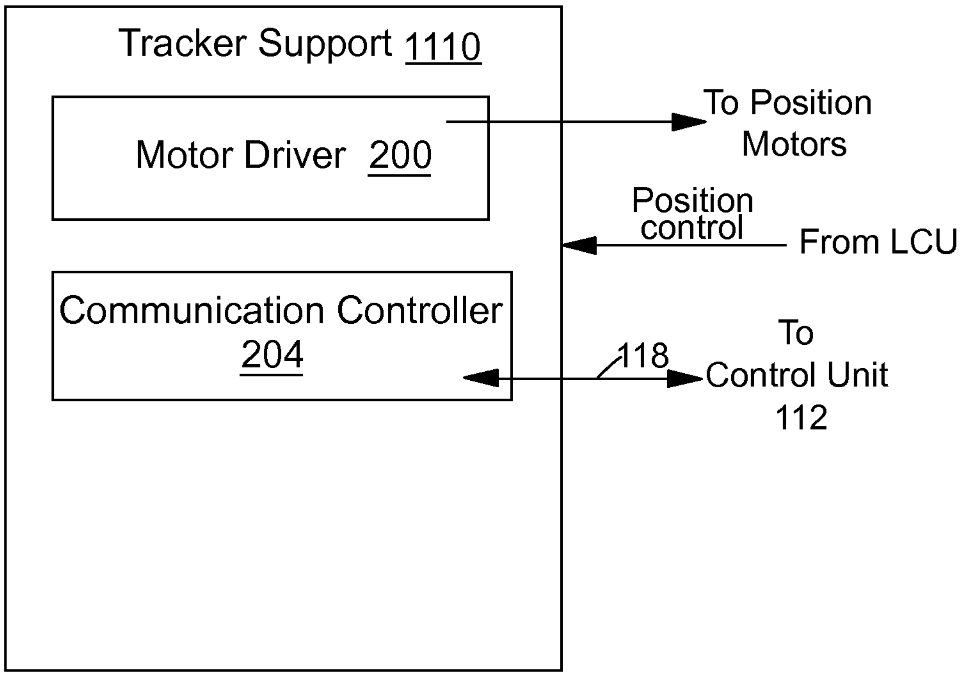

Tracker Support 1110
Motor Driver 200
To Position Motors
Position control
From LCU
Communication Controller 204
118
To Control Unit 112

FIG. 13

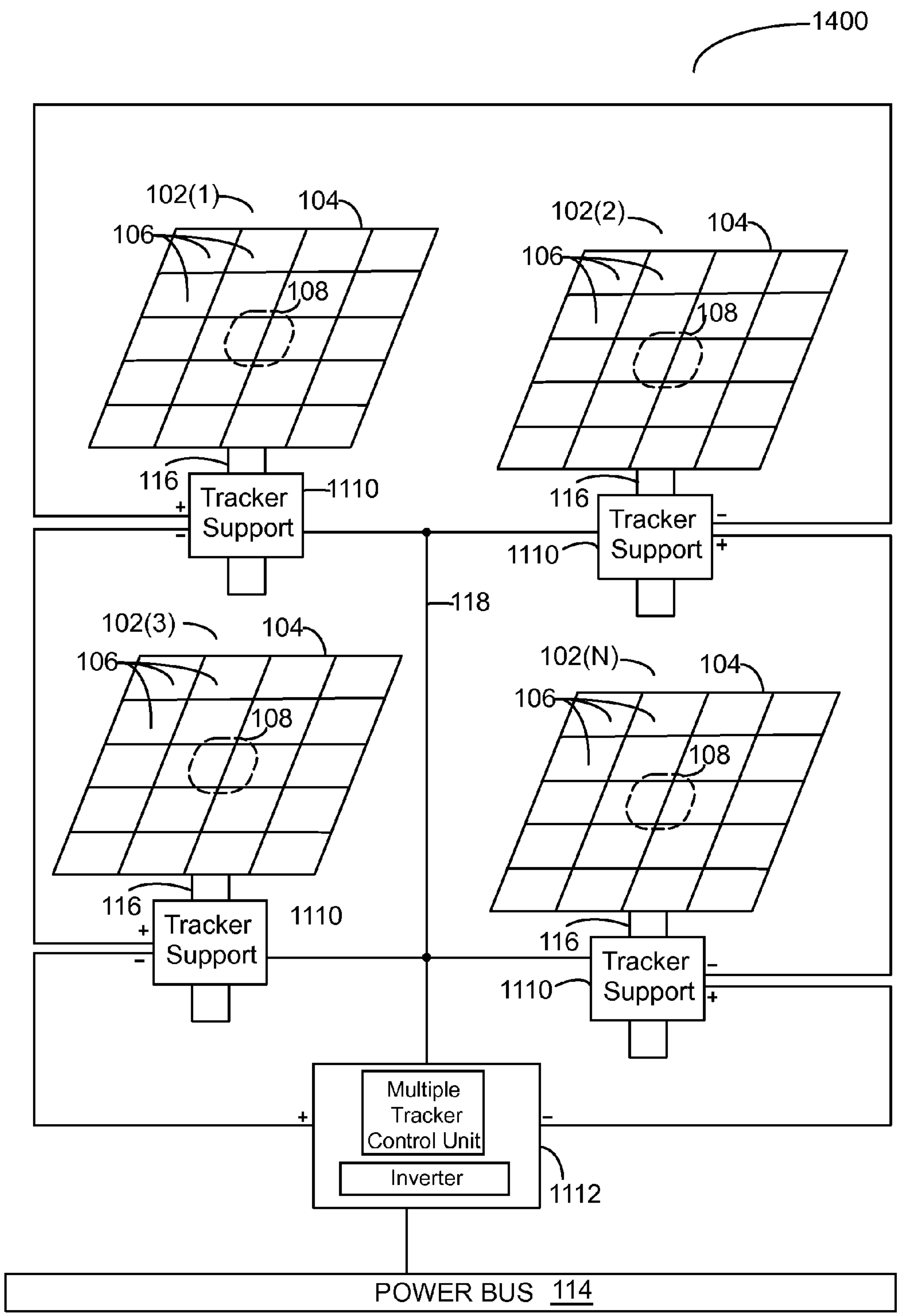

1400
102(1)
104
106
108
116
Tracker Support
1110
102(2)
104
106
108
116
Tracker Support
1110
118
102(3)
104
106
108
116
Tracker Support
1110
102(N)
104
106
108
116
Tracker Support
1110
Multiple Tracker Control Unit
Inverter
1112
POWER BUS 114

FIG. 14

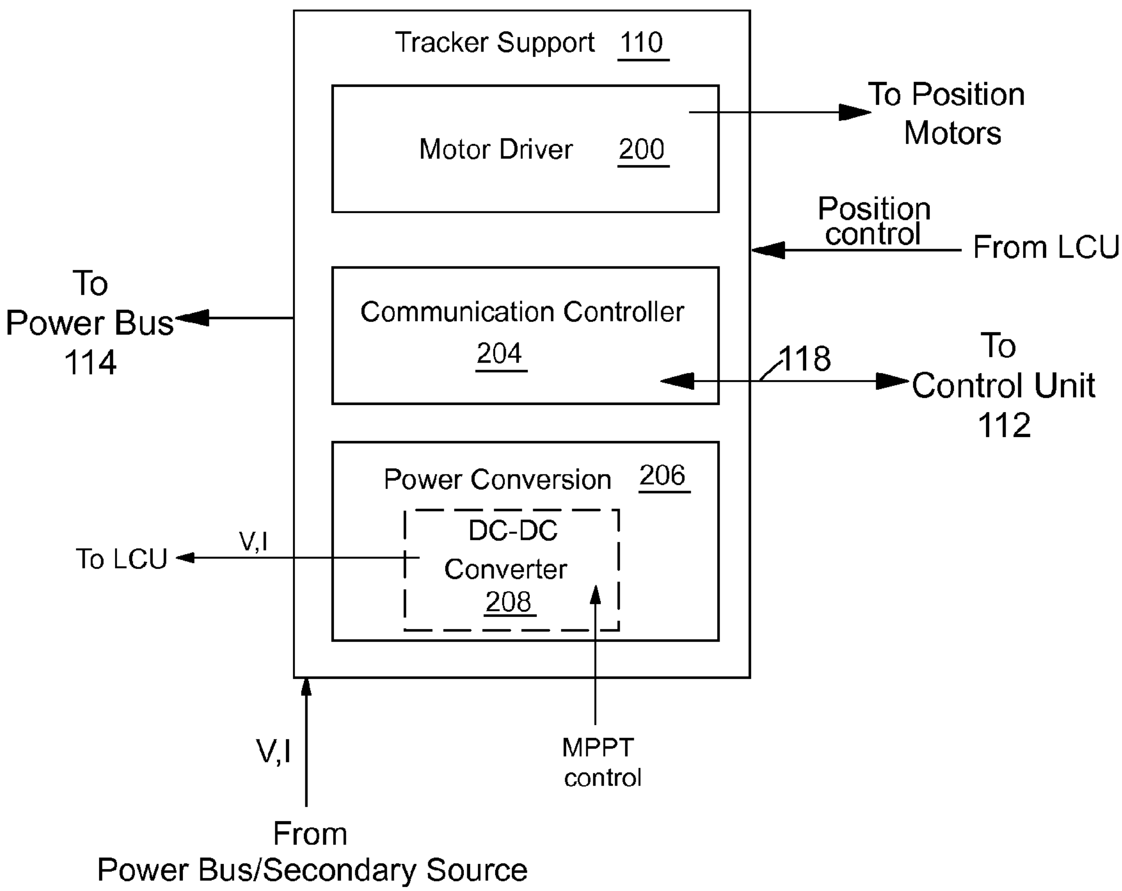
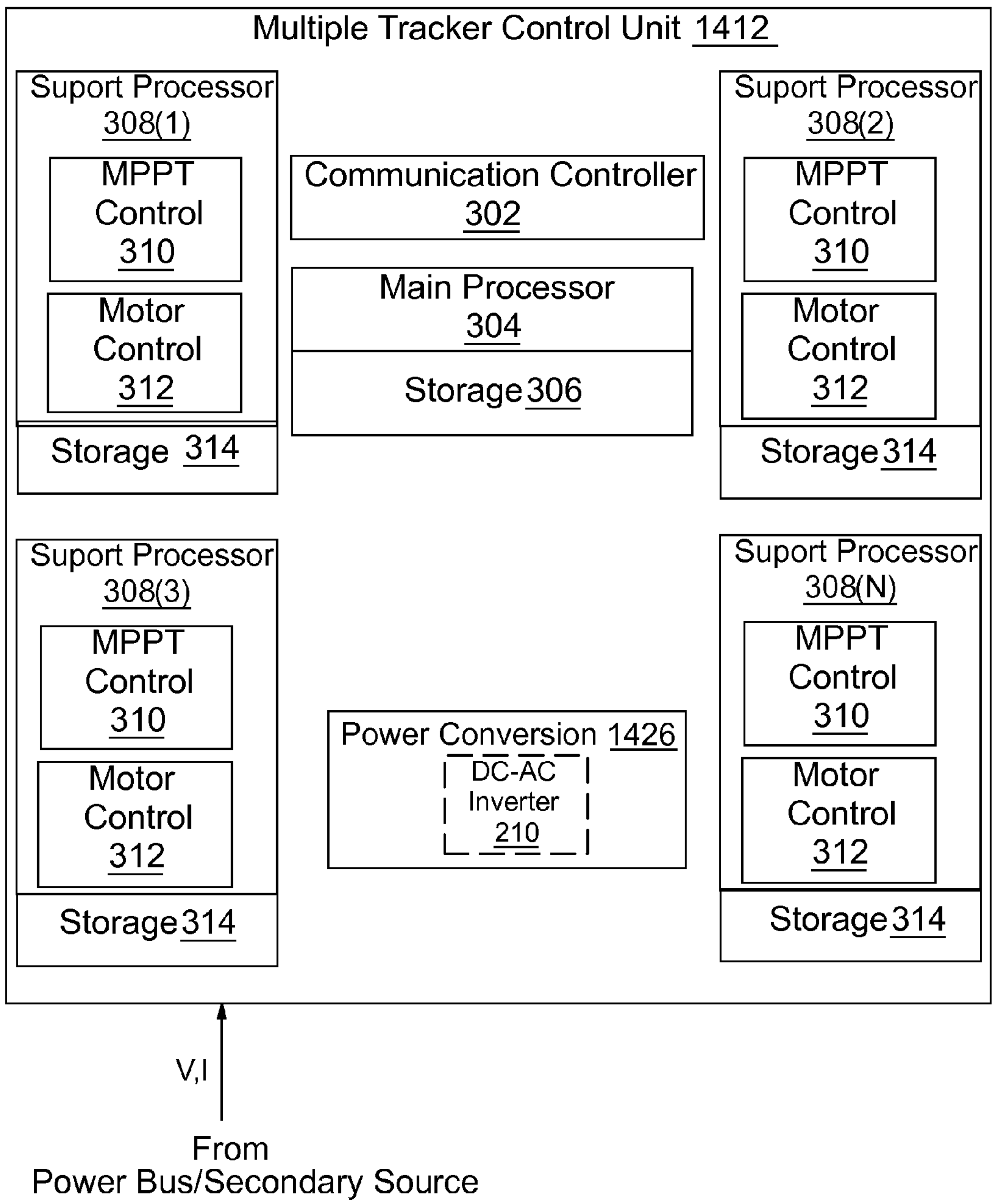

Tracker Support 110
Motor Driver 200
To Position Motors
Position control
From LCU
Communication Controller 204
To Power Bus 114
118
To Control Unit 112
Power Conversion 206
DC-DC Converter 208
V,I
To LCU
V,I
MPPT control
From Power Bus/Secondary Source

FIG. 15



Multiple Tracker Control Unit 1412
Suport Processor 308(1)
MPPT Control 310
Motor Control 312
Storage 314
Communication Controller 302
Main Processor 304
Storage 306
Suport Processor 308(2)
MPPT Control 310
Motor Control 312
Storage 314
Suport Processor 308(3)
MPPT Control 310
Motor Control 312
Storage 314
Power Conversion 1426
DC-AC Inverter 210
Suport Processor 308(N)
MPPT Control 310
Motor Control 312
Storage 314
V,I
From
Power Bus/Secondary Source

FIG. 16

PHOTOVOLTAIC GENERATING SYSTEM WITH CONTROL UNIT FOR CONTROLLING OUTPUT POWER CONVERSION AND ACTUATION OF PHOTOVOLTAIC TRACKER UNITS

This application claims the benefit of and priority to U.S. Patent Application No. 61/531,538 filed Sep. 6, 2011, the contents of which are incorporated herein by reference.

BACKGROUND

The present disclosure relates to solar energy systems that use either concentrated or non-concentrated photovoltaic units.

SUMMARY

According to an example embodiment, there is provided a maximum power point tracker controller configured to track an orientation of one or more subportions of a solar collector module to obtain a maximum solar radiation capture while also controlling a DC operating voltage for each of said one or more subportions.

According to one example is a photovoltaic (PV) generating system that includes a plurality of PV tracker units, each having: a PV panel with a plurality of PV generators connected to output electrical power and an actuator for positioning the PV panel. A multiple tracker control unit is in communication with the plurality of PV tracker units, the tracker control unit monitoring the output electrical power of the PV panels and controlling, in dependance on the monitored output electrical power, both: (i) power conversion of the output electrical power and (ii) the actuators of the PV tracker units, to optimize power output for the plurality of PV tracker units.

According to one example is a tracker control unit for controlling a plurality of PV tracker units that each have at least one PV panel with PV generators connected to output electrical power and an actuator for positioning the at least one PV panel, the tracker control unit being configured to monitor the output electrical power of the PV panels and control, in dependance on the monitored output electrical power, both: (i) power conversion of the output electrical power and (ii) the actuators of the PV tracker units, to optimize power output for the plurality of PV tracker units.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram illustration of a photovoltaic solar power generating system according to an example embodiment;

FIG. **2** is a block diagram illustration of a tracker support module used in the system of FIG. **1** according to an example embodiment;

FIG. **3** is a block diagram illustration of a multiple tracker control unit used in the system of FIG. **1** according to an example embodiment;

FIG. **4** is a block diagram illustration of a photovoltaic solar power generating system according to a further example embodiment;

FIGS. **5**A, **6**A, **7**A and **8**A are illustrations of current to voltage and FIGS. **5**B, **6**B, **7**B and **8**B are illustrations of angular acceptance showing calibration of the solar power generating system of FIG. **4**;

FIG. **9** is a flow diagram illustrating calibration of the solar power generating system of FIG. **4**;

FIG. **10** is a block diagram illustration of a multiple tracker control unit for application to the system of FIG. **1** according to a further example embodiment;

FIG. **11** is a block diagram illustration of a photovoltaic solar power generating system according to a further example embodiment;

FIG. **12** is a block diagram illustration of a multiple tracker control unit used in the system of FIG. **11** according to an example embodiment;

FIG. **13** is a block diagram illustration of a tracker support module used in the system of FIG. **11** according to an example embodiment;

FIG. **14** is a block diagram illustration of a photovoltaic solar power generating system according to yet another example embodiment;

FIG. **15** is a block diagram illustration of a tracker support module used in the system of FIG. **14** according to an example embodiment; and

FIG. **16** is a block diagram illustration of a multiple tracker control unit used in the system of FIG. **14** according to an example embodiment.

DESCRIPTION OF EXAMPLE EMBODIMENTS

FIG. **1** illustrates a solar power generating system **100** that includes multiple photovoltaic (PV) tracking units **102**(**1**)-**102**(N) (each referred to generically as PV tracking unit **102** or **102**(*j*), where 1<=j<=N), according to an example embodiment. In the illustrated embodiment of FIG. **1**, the system **100** includes four tracking units **102**, however the system could include more or less than four tracking units **102**. The system **100** can be a stand alone system or a sub-system integrated into a larger power generating plant.

In some embodiments, some or all of the tracker units **102**(**1**)-**102**(N) may be secured to a common ground mounted frame, such as that described in International Application No. PCT/IB2012/052723, by a tracker support member **116**. Each tracker unit **102** includes a dual axis tracker panel **104** that is mounted by an actuator **108** to the tracker support member **116**. In an example embodiment, the actuator **108** includes a pair of drive motors and an armature to pivot the tracker panel **104** about two axes (for example elevation and azimuth) to track sun position in the manner described below. Other drive configurations can also be used—for example the actuator **108** may include only a single motor geared to pivot the tracker panel **104** about one axis at a time. The tracker panel **104** includes an array of PV generators **106** for converting solar energy to electricity. In at least some example embodiments, PV generators **106** are concentrated PV modules that each includes a concentrating optical assembly, such as the light-guide solar panel described in U.S. Pat. No. 7,873,257, for concentrating incident sun rays onto a PV cell or receiver. The concentrating optical assembly could by way of example include lenses, reflectors, waveguides and other light-affecting components. Each tracker unit **102** includes a tracker support module **110** that includes electronics for performing DC-DC conversion or DC-AC inversion on power output from the unit's PV generators **106**, and also to drive the motor(s) of actuator **108**. Within each tracker unit **102** the PV generators **106** may be connected in series or parallel or a combination thereof to provide a collective power signal to tracker support module **110**. The tracker support module **110** is connected to output power to a system power bus **114**. The individual tracker units **102**(**1**)-**102**(N) can be connected in parallel or series or combinations thereof to the system power bus **114**.

The system **100** includes a multiple tracker control unit **112** that is connected by one or more communication links **118** to exchange information with the tracker support modules **110** of the tracker units **102**(**1**)-**102**(N). In an example embodiment, multiple tracker control unit **112** is an application specific integrated circuit (ASIC) which, as explained in greater detail below, is configured to support Maximum Power Point Tracking (MPPT) in parallel for the tracker units **102**(**1**)-**102**(N) as well as support mechanical tracking control in parallel for the tracker units **102**(**1**)-**102**(N).

With reference to FIG. **2**, the tracker support electronics of each tracker support module **110** will now be explained in greater detail. In at least some example embodiments each tracker support module **110** is located physically proximate to its respective tracker unit **102**—for example the electronics that make up support module **110** may be located on a circuit board or circuit boards located within one or more weatherproof enclosures or boxes that are physically secured to the support member **116** or other part of the tracker unit **102**. The tracker support module **110** includes motor driver **200**, communication controller **204** and power conversion controller **206**. Power conversion controller **206** may include a rectifier and DC/DC converter **208** for converting a variable non-constant current and a non-constant voltage received from PV generators **106** into a constant voltage or constant current signal for supply to the power bus **114**. Alternatively, the power conversion controller may include a DC-AC inverter **210** for converting the direct current signal received from PV generators **106** into an AC signal for supply to the power bus **114**. In an example embodiment, the power conversion module **206** exchanges signals through communication controller **204** and communications link **118** with the multi-tracker control unit **112**. In particular, the power conversion module **206** sends signals over link **118** that represent its output power (which for example could be signals that represent output current (I) and voltage (V)) to the multiple tracker control unit **112** and receives MPPT control signals back from the multiple tracker control unit **112** that control its operation to implement MPPT power conversion.

Motor driver **200** is configured to sense the position of tracker panel **104** and control the operation of the drive motor(s) of tracker panel actuator **108**. In one example embodiment the tracker panel actuator **108** includes two home position switches for providing position information to the motor driver **200**. In an example embodiment, the motor driver **200** exchanges signals through communication controller **204** with the multi-tracker control unit **112**. In particular, the motor driver **204** sends signals over link **118** that represent tracker panel position to the multiple tracker control unit **112** and receives position control signals back from the multiple tracker control unit **112** that control its operation to implement solar tracking.

In an example embodiment the communications link **118** between the tracker support module **110** and the multiple tracker control unit **112** may be implemented through power line communications (PLC) such that the same conductors used to provide power to the tracker unit **102** can also be used to facilitate signal communications with the multiple tracker control unit **112**, with communication controller **204** performing the function of a PLC interface. However, alternative wired or wireless communications links could be used, including for example a communications link employing the RS-485 standard.

Referring to FIG. **3**, an example embodiment of a multiple tracker control unit **112** will now be described in greater detail. The multiple tracker control unit **112** may be located near the tracker units **102**(**1**)-**102**(N)—for example, if tracker units **102**(**1**)-**102**(N) are mounted an a common support frame, the multiple tracker control unit **112** could be located on a circuit board within a weather-proof box or enclosure secured to the common support frame. However, in some embodiments the multiple tracker control unit **112** could be remotely located a distance away from its associated tracker units **102**(**1**)-**102**(N).

As noted above, in at least some embodiments the multiple tracker control unit **112** is implemented as an ASIC on a single silicon chip and is configured to support Maximum Power Point Tracking (MPPT) in parallel for the tracker units **102**(**1**)-**102**(N) as well as support mechanical tracking control in parallel for the tracker units **102**(**1**)-**102**(N). In this regard, the multiple tracker control unit **112** includes multiple processor cores on a single substrate, including a main processor core **304** that has associated storage **306** (which may for example be flash memory), and at least N support processor cores **308**(**1**)-**308**(N) (referred to generically herein as support processor core **308** or **308**(*j*), where 1<=j<=N), each having an associated storage **314** (which may for example be flash memory). The support processor cores **308**(**1**)-**308**(N) are configured to operate in parallel, with each of the processor cores **308**(**1**)-**308**(N) supporting a respective tracker unit **102**(**1**)-**102**(N), enabling the multiple tracker control unit **112** to control multiple tracker units **102** simultaneously. In some embodiments, the main processor core **304** is larger and more powerful than the support processor cores **308**(**1**)-**308**(N)—by way of non-limiting example, the main processor core **304** could be a 32-bit core, whereas the support processor cores **308**(**1**)-**308**(N) are each 8-bit cores.

In the illustrated embodiment, the multiple tracker control unit **112** includes a communication controller **302** for controlling communications over the communication link **118** between the multiple tracker control unit **112** and the respective tracker units **102**(**1**)-**102**(N). The main processor core **304** controls and monitors the performance of each of the support processor **308**(**1**)-**308**(N) and in at least some examples provides performance information through communications link **118** (or a different communications link) to a remote control station **330** that monitors a plurality of multiple tracker control units **112**.

Each support processor **308**(*j*) is configured to implement an MPPT control function **310** in order to control power conversion at its respective tracker unit. In this regard, the support processor **308**(*j*) receives a signal or signals representing the output power (for example voltage (V) and current (I)) as produced by the power conversion module **206** for its respective tracker unit **102**(*j*). The MPPT control function **310** implements any acceptable MPPT control algorithm (acceptable algorithms include but are not limited to one or more of: perturb and observe, incremental conductance, constant voltage and current feedback) and provides MPPT control signals that are transmitted back through communications link **118** to the power conversion module **206** of tracker unit **102**(*j*) in order to achieve electrical MPPT for the tracker unit **102**(*j*).

The PV tracker panels **104** have mechanical acceptance angles relative to the sun's rays, and accordingly each support processor **308**(*j*) is further configured to implement a tracker motor control function **312** in order to control the orientation of the tracker panel **104** of its respective tracker unit **102**(*j*) to optimize PV panel efficiency. The motor control function **312** implements a tracking algorithm to generate position control signals that are transmitted over communications link **118** to the motor driver **200** of its respective tracker unit **102**(*j*).

In one example embodiment, the tracking algorithm used by motor control function **312** is a hybrid or calibrated open-loop method for optimizing panel positioning or trajectory. In particular, astronomical data and tracker location and position information is stored in the storage of the control unit **112** or accessible to the multiple tracker control unit **112** such that the motor control function **312** can calculate the sun's position relative to the tracker panel **104** and a target panel position (for example azimuth and elevation) in order to adjust the panel position to track the sun through the course of a day. In order to further improve tracking accuracy and adjust for any manufacturing or assembly variations of the tracker unit **102**(*j*) or uneven terrain or imperfect installation, the motor control function **312** is further configured to perform a calibration function to correct the open-loop trajectory used by the motor control function **312**. In this regard, during a trajectory calibration cycle, the tracker motor control function **312** of the support processor **308**(*j*) also receives a signal or signals representing the output power (for example one or both of voltage (V) and current (I)) as produced by the power conversion module **206** for its respective tracker unit **102**(*j*). During the calibration cycle, the tracker motor control function **312** acquires calibration data at a series of panel positions as the PV panel moves through its default trajectory over a predetermined time period (by way of non-limiting example, calibration data could be obtained six to twelve times a day for a period of 1-3 days). At each of the calibration data sample points, panel alignment is adjusted relative to the position calculated based on astronomical data to determine at which panel elevation and azimuth the instantaneous power output from power conversion module **206** is maximized. By way of example, the elevation and azimuth may each be individually incrementally adjusted until the maximum or optimum power for each movement axis is determined for the sample point. Using such information, a calibrated trajectory is calculated for the tracker unit **102**(*j*), and the calibrated trajectory subsequently used as the default trajectory by the motor control function **312** to control the operation of the motor driver **200** of its respective tracker unit **102**(*j*).

The calibration routine may automatically be performed on post-installation system setup, or may be manually triggered locally or remotely by an operator. In some examples the calibration routine may be periodically performed automatically after a predetermined period elapses or a predetermined trigger event occurs. In some example embodiments, one or more of the support processor core **308**(*j*), the main processor core **304**, or a remote controller may be configured to track if the instantaneous power output for a tracker unit **102**(*j*) falls below threshold performance levels and cause the calibration routine to be automatically performed as a result. In some example embodiments, the tracker control unit may be automatically configured to perform the calibration routine on start up after the solar power generating system has detected and been subjected to a climate event such as a wind storm.

In some example embodiments, the motor control function **312** may be configured to implement closed-loop tracking in which PV tracking unit output power is monitored on an on-going basis and motor driver **200** controlled to continuously or nearly continuously maximize instantaneous power output for a tracker unit **102**(*j*).

In an alternative example embodiment, rather than using instantaneous power as a tracking input, a sun sensor could be provided on each of the solar tracker panels **104** and the information from the sun sensor provided to the motor control functions **312** of support processor cores **308**(**1**)-**308** (N) in place of the power output of power conversion module **206**. In some example embodiments, the input from a sun sensor could be used to supplement instantaneous power information as a tracking input to motor control function **312**.

The tracker support units **110** and the multiple tracker control unit **112** can draw power from the power bus **114**, or they may be powered by secondary PV cells, batteries or any other secondary source of power.

FIG. **4** discloses a further embodiment of a solar power generating system **400** that is substantially identical to the above-described solar power generating system **100** except for differences that will be apparent from the Figures and the following description. In solar power generating system **400**, the tracker units **102**(**1**)-**102**(N) are paired up with one pair of units **102**(**1**) and **102**(**2**) connected in series, the other pair of units **102**(**3**) and **102**(N) connected in series, and the two pairs connected in parallel. In solar generating system **400**, the tracker position calibration routine used to establish panel trajectory is performed jointly for each serially connected tracker unit pair. In this regard, the multiple tracker control unit **112** receives as inputs the signals representative of output current $Ipair_1$ for serially connected tracker units **102**(**1**) and **102**(**2**) and the output current $Ipair_2$ for serially connected units **102**(**3**) and **102**(N The presently described calibration routine may in some applications permit two tracker units, with panels **104** wired in series, to remain operational while being calibrated by monitoring the output current of the panel pair, thereby allowing the tracker panels **104** to continue producing power throughout calibration with only relatively minor losses.

An example of a tracker trajectory calibration performed by the tracker control unit **112** to obtain calibration data for a calibration point for serially connected tracker units **102**(**1**) and **102**(**2**) will be described with reference to the illustrations shown in FIGS. **5**A-**8**B. The illustrations in FIGS. **5**A, **6**A, **7**A and **8**A represent the IV curve of the pair of tracker units **102**(**1**) and **102**(**2**) and the illustrations in FIGS. **5**B, **6**B, **7**B, and **8**B represent output power vs. angle, or angular acceptance, of the panels **104** of the pair of tracker units **102**(**1**) and **102**(**2**). The multiple tracker control unit **112** receives as an input a representation of the current $Ipair_1$ at the Maximum Power Point (MPP) for the pair of panels **104** of tracker units **102**(**1**) and **102**(**2**). From FIG. **5**A it is evident that the two panels of tracker units **102**(**1**) and **102**(**2**) are uncalibrated and misaligned relative to one another. The calibration begins by picking one axis of the actuator **108** of tracker unit **102**(**1**) and moving it in an arbitrary direction—by moving the panel and comparing power from different angles an angular acceptance pattern can be determined. As shown by the triangular marker **500** in the angular acceptance illustration (FIG. **5**B) that corresponds to the illustration of FIG. **5**A, panel **104** of tracker unit **102**(**1**) is not perfectly aligned with the sun even though it is outperforming the panel **104** of tracker unit **102**(**2**). In FIG. **6**A, the panel **104** of tracker unit **102**(**1**) has been moved far enough out of alignment to register a drop in MPP (which can be measured using the current $Ipair_1$). Note that initially, the MPP for the pair of panels would not have moved because the panel **104** of tracker unit **102**(**1**) was performing better than panel **104** of tracker unit **102**(**2**). Only when the performance of the panel of tracker unit **102**(**1**) drops below that of the panel of tracker unit **102**(**2**) would the current $Ipair_1$ drop, representing a drop in MPP.

FIG. **6**B illustrates how far the panel of tracker unit **102**(**1**) has deviated from perfect alignment. Once a pre-defined drop in power (as indicated by $Ipair_1$ and illustrated in FIG. **6**B by triangular marker **502**) has been detected by multiple tracker control unit **112**, the multiple tracker control unit **112** will drive the tracker actuator **108** of tracker unit **102**(**1**) to move the tracker panel of unit **102**(**1**) in the other direction (on the same axis). In FIG. **7**A, the tracker panel of unit **102**(**1**) has moved all the way past its optimal alignment until the current $Ipair_1$ indicates the same pre-defined performance drop as in FIG. **6**A (as illustrated by triangular marker **504** in FIG. **7**B). The optimal alignment for the axis is estimated to be directly between the tracker panel location in FIGS. **6**B and **7**B as illustrated by triangular marker **506** shown in FIG. **8**B. In FIGS. **8**A, **8**B the tracker panel **104** of tracker unit **102**(**1**) is optimally aligned, however the MPP remains unchanged until the same calibration is carried out for the panel **104** of tracker unit **102**(**2**). The calibration process illustrated in FIGS. **5**A-**8**B needs to be repeated for both axes of each tracker panel. In some embodiments, the process can be repeated closer and closer to the estimated position for optical alignment for each axis in order to fine tune the calibration. FIG. **9** represents the calibration routine illustrated by FIGS. **5**A-**8**B in a flow diagram as calibration process **900**. During calibration process **900**, the tracker control unit **122** controls the power conversion modules **206** of the respective panels to provide electrical MPPT power conversion throughout the calibration process.

The calibration process **900** is implemented by multiple tracker control unit **112**, which receives as inputs panel position information from the tracker support units **110** of the respective tracker units **102**(**1**)-**102**(N) and MPP feedback information for each panel pair in the form of $Ipair_1$ and $Ipair_2$. Based on these inputs, the multiple tracker control unit **112** provides control signals to the respective tracker support units **110** to control MPPT power conversion at the tracker unit power conversion modules **206** and control the tracker unit motor drivers **200**.

The calibration process **900** of FIG. **9** can be carried out periodically during a system calibration period to set a number of measured calibration data points that can be used to adjust an astronomically based trajectory—by way of non-limiting example, as with system **100**, the calibration process **900** could be performed at six to twelve trajectory points a day for a period of 1-3 days. As indicated at action **904**, the first panel of serially connected tracker units **102**(**1**) and **102**(**2**) is moved in one direction along a first axis (for example the elevation axis) until the panel pair output power drops a predetermined amount and the corresponding panel angle A**1** recorded, after which the first panel is moved in the opposite direction along the same axis until the panel pair output power equals that of panel angle A**1** and the corresponding panel angle B**1** is recorded (action **906**). The optimal panel alignment for the first axis for the first panel is set to be directly between A**1** and B**1** (action **908**). The optimal panel alignment for the second axis (for example the azimuth) for the first panel is then determined in a similar manner: the panel of tracker unit **102**(**1**) is moved in one direction along the second axis until the output power for the panel pair drops a predetermined amount and the corresponding panel angle A**2** is recorded (action **912**), after which the first panel is moved in the opposite direction along the same axis until the panel pair output power equals that of the panel angle A**2** and the corresponding panel angle B**2** is recorded (action **914**). The optimal panel alignment for the second axis for the first panel is set to be directly between A**2** and B**2** (action **916**). Actions **904**-**916** are then repeated for the second panel in the serially connected pair—panel **104** of tracker unit **102**(**2**) (action **918**), and then the process repeated again for the next serially connected pair—tracker units **102**(**3**) and **102**(N) (using $Ipair_2$ as the power input for calibration of tracker units **102**(**3**) and **102**(N)).

The process **900** can in some applications be appropriate for imperfect optics in CPV systems having an asymmetric angular acceptance because it is conservative to align the panel to the half-way point between the two shoulders of the angular acceptance illustration.

Although system **100** shows four panels connected in parallel and system **400** includes two parallel connected pairs of serially connected panels, the calibration and control methods described herein could also be configured for different numbers of panels and different series/parallel panel configurations.

In an example embodiment, the calibration algorithm for each tracking unit **101**(*j*) is carried out by the corresponding support processor core **308**(*j*) of the multiple tracker control unit **112**. In some alternative example embodiments, the calibration algorithm for each tracking unit **101**(*j*) is carried out at the main processor core **304**, with post-calibration tracking control being provided by the respective support processor cores **308**(*j*). In the above-described embodiments, the multiple tracker control unit **112** is shown as having a support processor core **308**(*j*) for each tracker unit **102**(*j*). However, in some alternative embodiments, the number of support processor cores **308** could be less than the number of tracker units **102**, with at least some support processor cores **308** supporting MPPT and tracker trajectory calculations for multiple tracker units **102**. Additionally, in some alternative embodiments, the multiple tracker control unit **112** could include multiple support processor cores **308** to control each tracker unit **102**—for example one support processor core **308** could be used to implement MPPT power conversion function **310** for a tracker unit and another support processor core **308** used to implement tracker trajectory calibration and control function **312** for the same tracker unit.

In some example embodiments, some of the electronics of the individual tracker support units **110** may be moved from the tracker units **102** to the multiple tracker control unit **112**. In this regard, FIG. **10** shows a block diagram of an alternative embodiment of a multiple tracker control unit **1000** that is substantially identical to multiple tracker control unit **112** with the exception of differences that will be apparent from the Figures and the following description. In multiple tracker control unit **1000**, the motor driver module **200** and power conversion module **206** electronics from each of the tracker units **102**(**1**)-**102**(N) have been moved from respective tracker support units **110** to the multiple tracker control unit **112**. A configuration such as shown in FIG. **10** could be appropriate in lower power systems where the inverter **210** and/or converters **208** included in the electronics of power conversion module **206** can be adequately temperature controlled. In some example embodiments, the electronics to implement motor driver module **200** can be moved to the multiple tracker control unit **112** independent of the electronics for implementing power conversion module **206**, and vice versa.

As described above, in an example embodiment, multiple tracker control unit **112** and tracker control unit **1000** are each implemented as a multi-processor core single chip ASIC. However, in some example embodiments the multiple tracker control unit **112** and tracker control unit **1000** could each be implemented as a chip set of multiple chips secured to a substrate such as a circuit board.

FIGS. **11-13** disclose a further embodiment of a solar power generating system **1100** that is similar to the above-described solar power generating system **100** except for differences that will be apparent from the Figures and the following description. In solar power generating system **1100** shown in FIG. **11**, the tracker units **102(1)**-**102**(N) are connected in series. In the illustrated embodiment, the multiple tracker control unit includes a central power conversion module **1126**. The single power conversion module **1126** may include a DC/DC converter for regulating the voltage or current of all the tracker units **201(1)**-**102**(N) and a DC/AC inverter for converting the direct current signal received from PV generators **106** into an AC signal for supply to the power bus **114**. A corresponding simplified tracker support unit **1110** is shown in FIG. **13**, which does not include the power conversion module **206** electronics. In the embodiment shown in FIGS. **11-13**, the support processor cores **308** transmit and receive motor control signals via the communication controllers **204**, **302** and communications link **118** to communicate with the motor driver **200** of the tracker support **1110**.

FIGS. **14-16** disclose a further embodiment of a solar power generating system **1400** that is similar to the above-described solar power generating system **1100** except for differences that will be apparent from the Figures and the following description. As shown in the block diagram of FIG. **14**, the tracker support units **1210** are connected in series. Each of the tracker support units **1210** are provided with a power conversion module **1406** with a DC-DC converter **208** as shown in FIG. **15**, and the power conversion module **1426** of the multiple tracker control unit **112** includes a central DC/AC inverter as shown in FIG. **16**. The communication controller **204** transmits signals that represent the power output from the power conversion module **1406** over link **118** to the multiple tracker control unit **1412** and receives MPPT control signals back from the multiple tracker control unit **1412** for implementation of MPPT power conversion by the power conversion module **1406**. The central DC/AC inverter **210** of the multiple tracker control unit **1412** converts the direct current signal received from the DC-DC converters **208** into an AC signal for supply to the power bus **114**.

At least some example embodiments of this invention provide an integrated circuit (chip or chipset) that accommodates a single or a plurality of Maximum Power Point Tracking (MPPT) DC/DC converters and/or MPPT DC/AC inverters as well as a single or a plurality of mechanical solar panel positioning tracker controllers, which consist of motor driver support electronics, sensory management, microprocessor control with adaptive, learning and auto-calibrating algorithms, onto a single System on Chip (SoC).

The integration of solar tracker functionality with one or more MPPT DC/DC and/or MPPT DC/AC power optimizers with their support chip sets onto a single SoC for controlling a solar collection module can comprise a plurality of solar collection panels in a single assembly. In at least some applications, the system on chip will be able to control solar trackers as well as controlling the power conversion of single or multiple solar power systems. Incorporating discrete components into a single ASIC solution can in some applications reduce form factor, costs, and failure modes within the system.

The SoC can have the ability to perform parallel MPPT on several different photovoltaic sources. It is also appropriate to have the maximum power point from the power optimization portion to calibrate or drive the solar tracker so that it will follow the sun without being affected by mechanical, electrical, and environmental offsets. The SoC incorporates integrated communication areas, such as power line communication, and/or RS485 can be embedded within the chipset allowing a very versatile easily deployable system for a wide variety of applications.

The main CPU (processor core) communicates internally with other processor(s) that govern the maximum power point tracking and DC-DC/AC conversion portion and provide information such as power production of the panels to the main controller. The main controller then uses this information to process and calibrate its primary responsibility, which is the tracker controls. Information such as maximum power point of the panel can calibrate mechanical, electrical and environmental offsets so that the tracker can function in any environment. The large thermal components from power conversion circuitry such as the motor driver H-Bridges and DC-DC conversion FETs can also be integrated. Multiple processor cores to drive multiple tracker solutions are also possible, which can provide parallel control rather than a sequential control based system.

The entire system can thus provide an enhanced level of tracking control allowing a wide range of compensation to improve the tracking accuracy throughout the life cycle of the solar power system.

The above description is intended to describe example embodiments of the invention from which numerous variations and modifications are possible.

The invention claimed is:

1. A photovoltaic (PV) generating system comprising:

a plurality of PV tracker units, each comprising:

at least one PV panel comprising a plurality of PV generators connected to output electrical power; and

an actuator for positioning the at least one PV panel in two axes;

at least one of the PV panels being connected in series with another of the PV panels to form a serially connected PV panel pair;

a multiple tracker control unit in communication with the plurality of PV tracker units, the tracker control unit monitoring the output electrical power of the PV panels and controlling, in dependence on the monitored output electrical power, both: (i) power conversion of the output electrical power and (ii) the actuators of the PV tracker units, to optimize power output for the plurality of PV tracker units,

the multiple tracker control unit being configured to perform a calibration routine during which a calibrated trajectory for each PV panel is calculated in dependence on the output electrical power therefrom, and wherein power conversion of the output electrical power from each PV panel comprises performing a DC-DC conversion to output a substantially constant voltage electrical power output signal, wherein the calibration routine comprises, for each serially connected pair of PV panels:

acquiring calibration data for each of the PV panels of the PV panel pair at a plurality of sample positions along respective predetermined trajectories of movement of the PV panels by:

at each sample position: (i) monitoring the power output from the PV panel pair as the orientation of a first one of the PV panels is incrementally varied in opposite directions relative to a first axis and determining for the first axis the orientation of the first one of the PV panels at which the monitored power is optimized; (ii) monitoring the power output from the PV panel pair as the orientation of the first one of the PV panels is incrementally varied in opposite directions relative to a second axis and determining for the second axis the orientation of the first one of the PV panels at which the monitored power is optimized; (iii) monitoring the power output from the PV panel pair as the orientation of a second one of the PV panels is incrementally varied in opposite directions relative to a first axis and determining for the first axis the orientation of the second one of the PV panels at which the monitored power is optimized; (iv) monitoring the power output from the PV panel pair as the orientation of the second one of the PV panels is incrementally varied in opposite directions relative to a second axis and determining for the second axis the orientation of the second one of the PV panels at which the monitored power is optimized; and

adjusting the predetermined trajectory in dependence on the calibration data to derive the calibrated trajectory.

2. The PV generating system of claim **1** wherein the multiple tracker control unit comprises a single chip integrated circuit (IC) controlling both the power conversion and the actuators of the PV tracker units to optimize power output for the plurality of PV tracker units.

3. The PV generator system of claim **2** wherein the IC comprises multiple processor cores including processor cores that are each associated with a respective PV tracker unit and perform calculations controlling the power conversion of electrical power therefrom.

4. The PV generator system of claim **3** wherein the processor cores that perform calculations controlling the power conversion are configured to perform maximum power point tracking for their associated PV tracker units.

5. The PV generator system of claim **2** wherein the IC comprises, for each PV tracker unit, one or both of an on-chip DC-DC converter or DC-AC inverter performing the power conversion.

6. The PV generator system of claim **2** wherein the IC comprises one or both of (i) a DC/DC converter for regulating the voltage or current of a plurality of the PV tracker units; and (ii) a DC/AC inverter for converting a direct current signal received from a plurality of the PV tracker units into an AC signal for supply to a power bus.

7. The PV generator system of claim **2** wherein each PV tracker unit comprises a DC/DC converter for regulating the voltage or current of the PV tracker unit; and the IC comprises a DC/AC inverter for converting direct current signal received from a plurality of the PV tracker units into an AC signal for supply to a power bus.

8. The PV generator system of claim **2** wherein each processor core associated with a PV tracker unit controls a trajectory of the actuator of its associated PV tracker unit.

9. The PV generator system of claim **8** wherein the IC comprises on-chip motor driver circuits for driving the actuators of the PV tracker units.

10. The PV generator system of claim **1** wherein the PV tracker units each include an associated tracker support circuit that communicates over one or more communication links with the multiple tracker control unit, each tracker support circuit comprising a motor driver for driving the actuator of the associated PV tracker unit and a power conversion circuit including a DC-DC converter or a DC-AC inverter, the motor driver and the power conversion circuit operating under control of signals received from the multiple tracker control unit.

11. The PV generator system of claim **10** wherein the one or more communication links include a power line communications link.

12. The PV generating system of claim **1** wherein the multiple tracker control unit comprises multiple processor cores in a chipset carried on a common substrate collectively controlling both the power conversion and the actuators of the PV tracker units to optimize power output for the plurality of PV tracker units.

13. A tracker control unit for controlling a plurality of PV tracker units that each have at least one PV panel with PV generators connected to output electrical power and an actuator for positioning the at least one PV panel in two axes, at least one of the PV panels being connected in series with another of the PV panels to form a serially connected PV panel pair, the tracker control unit being configured to monitor the output electrical power of the PV panels and control, in dependence on the monitored output electrical power, both: (i) power conversion of the output electrical power and (ii) the actuators of the PV tracker units, to optimize power output for the plurality of PV tracker units,

the tracker control unit being configured to perform a calibration routine during which a calibrated trajectory for each PV panel is calculated in dependence on the output electrical power therefrom, and wherein power conversion of the output electrical power from each PV panel comprises performing a DC-DC conversion to output a substantially constant voltage electrical power output signal, wherein the calibration routine comprises, for each serially connected pair of PV panels:

acquiring calibration data for each of the PV panels of the PV panel pair at a plurality of sample positions along respective predetermined trajectories of movement of the PV panels by:

at each sample position: (i) monitoring the power output from the PV panel pair as the orientation of a first one of the PV panels is incrementally varied in opposite directions relative to a first axis and determining for the first axis the orientation of the first one of the PV panels at which the monitored power is optimized; (ii) monitoring the power output from the PV panel pair as the orientation of the first one of the PV panels is incrementally varied in opposite directions relative to a second axis and determining for the second axis the orientation of the first one of the PV panels at which the monitored power is optimized; (iii) monitoring the power output from the PV panel pair as the orientation of a second one of the PV panels is incrementally varied in opposite directions relative to a first axis and determining for the first axis the orientation of the second one of the PV panels at which the monitored power is optimized; (iv) monitoring the power output from the PV panel pair as the orientation of the second one of the PV panels is incrementally varied in opposite directions relative to a second axis and determining for the second axis the orientation of the second one of the PV panels at which the monitored power is optimized; and

adjusting the predetermined trajectory in dependence on the calibration data to derive the calibrated trajectory.

14. The tracker control unit of claim **13** comprising a single chip integrated circuit (IC) configured to control both the power conversion and the actuators of the PV tracker units to optimize power output for the plurality of PV tracker units.

15. The tracker control unit of claim **14** wherein the IC comprises multiple processor cores including processor cores that are each associated with a respective PV tracker unit and perform calculations controlling the power conversion of electrical power therefrom.

16. The tracker control unit of claim **15** wherein the processor cores that perform calculations controlling the power conversion are configured to perform maximum power point tracking for their associated PV tracker units.

17. The tracker control unit of claim **14** wherein the IC comprises at least one of on-chip DC-DC converters or on-chip DC-AC inverters performing the power conversion.

18. The tracker control unit of claim **14** wherein the IC comprises on-chip motor driver circuits for driving the actuators of the PV tracker units.

19. The tracker control unit of claim **14** wherein the multiple tracker control unit comprises multiple processor cores in a chipset carried on a common substrate collectively controlling both the power conversion and the actuators of the PV tracker units to optimize power output for the plurality of PV tracker units.

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